AN OCCLUDING WAVE, OCTOBER 7, 1951

J. A. CARR

WBAN Analysis Center, U. S. Weather Bureau, Washington, D. C.

INTRODUCTION

On October 7, 1951, an open wave (fig. 1) moved across northwestern Ohio toward Detroit, Mich., and developed into a storm with an occluded front extending 300 miles from the low center (fig. 2). The favorable location of this storm relative to the observational network while occluding suggested that this would be a suitable case for more detailed study than is usually possible. Too frequently the larger scale picture captures our attention to the exclusion of the smaller scale features which are an essential part of the over-all processes.

The following discussion will describe the results of an hourly analysis of both the cold front and the warm front as they moved across eastern Ohio and western Pennsylvania and occluded.

In the examination of the frontal motions it became apparent that the topography had exerted considerable influence upon the occlusion process. Furthermore, it was found that the two air masses in moving over the same geographical features failed to exhibit the same reactions. These two findings form the basis of this article.

BACKGROUND INFORMATION

In order to discuss the motion of the fronts it is necessary to know their positions 6 hours after the map time of figure 1. At 1830 GMT, 65 to 70 miles of front had occluded along a line extending east and southeast from the low center, just east of Detroit, to the middle of Lake Erie. From this last point a cold front could be traced to the shore line 30 miles southwest of the Ohio-Pennsylvania border. Continuing southward the cold front extended through Youngstown, Ohio, and Wheeling, W. Va., to a location about 15 miles east of Charlestown, W. Va., where, for convenience, it can be disregarded for the purposes of this article.

Going back and picking up the warm front at the point of separation from the cold front, over the Lake, it can be followed to the south shore where it intersected the land just southwest of Erie, Pa. From Erie it continued southeast and southward to the west of Blairsville, Pa., south through a point mid-way between Elkins and Petersburg, W. Va., to a position east of Roanoke, Va., where it ceases to be important to this article.

Most of the following discussion on the behavior of the fronts is based upon a series of maps drawn for the data obtained from the hourly sequences for the area including western Pennsylvania, eastern Ohio, and southwestern New York.

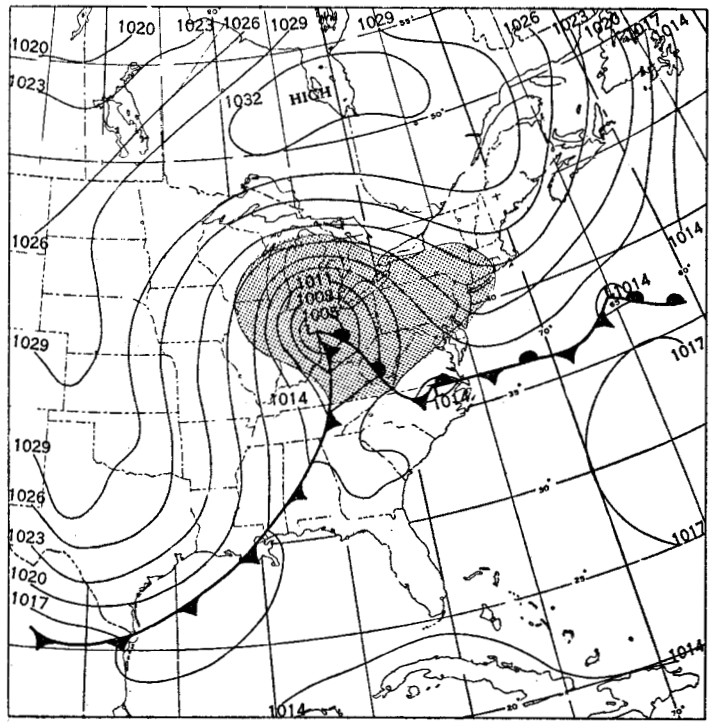

FIGURE 1—Surface weather chart, 1230 GMT, October 7, 1951. Shading indicates areas of active precipitation.

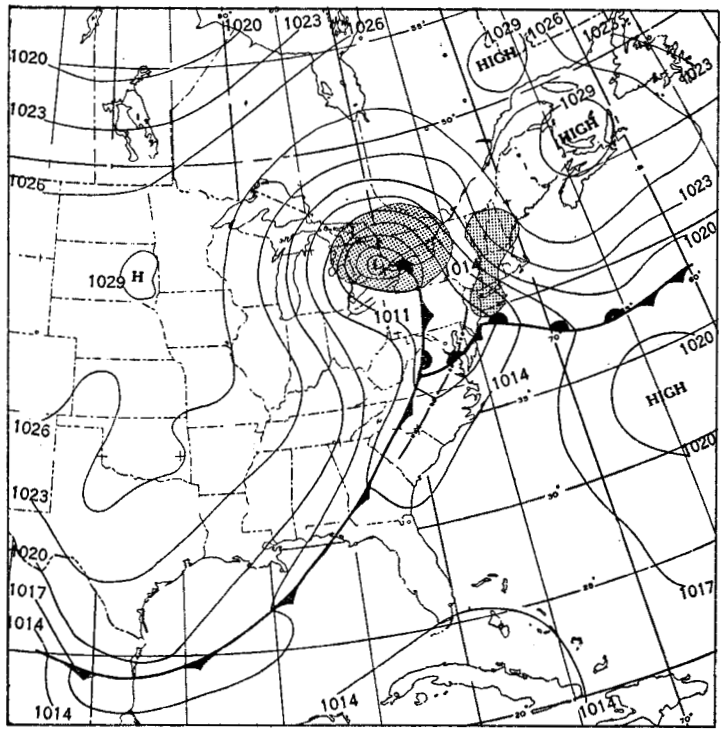

FIGURE 2—Surface weather chart, 0030 GMT, October 8, 1951.

Before proceeding further it is useful to have a knowledge of the movement of the fronts prior to 1830 GMT. To determine the speed of the fronts on a comparative basis a line was drawn through Erie, Pa., so oriented as to be approximately parallel to the direction of motion of the Low, i. e., southwest-northeast. A second line was drawn parallel to the first, connecting Cincinnati, Pittsburgh, and Blairsville, Pa. In the following discussion these lines will be referred to as the Erie or Pittsburgh line and any motion of the warm, cold, or occluded fronts will be as measured along either line. With this arrangement the fronts moved in such a direction as to render the Erie or Pittsburgh lines normal to the fronts.

For 6 hours prior to 1830 GMT the cold front moved at an average speed of 30 m. p. h. along the Erie line and 29 m. p. h. along the Pittsburgh line. In this same period the warm front moved at an average speed of 27 m. p. h. along the Erie line and 26 m. p. h. along the Pittsburgh line. As usual uncertainties arise when an attempt is made to measure the progress of a front on a weather map; but dividing the time interval into two 3-hourly periods, there is a difference along both lines between the first and second periods. Along both lines the rates of movement decreased during the last 3 hours and reference to a map would show that the fronts were approaching the Pennsylvania border where the topography rises rapidly.

HOURLY MOVEMENT OF THE FRONTS

At 1930 GMT, the warm front advance for one hour measured 25 miles along the Erie line and only 18 miles along the Pittsburgh line. Compared with the 6-hour rates, the higher value indicates the small retardation of a front moving over comparatively open country while the smaller value indicates the influence of the rough countryside to the west of Blairsville.

During this same hour the cold front was still travelling across relatively flat country and the eastward displacement measured about 38 miles along the Erie line and 40 miles for the Pittsburgh section. These values, of course, don't seem to support increasing influence of the terrain. In spite of numerous attempts to reinterpret the data on the maps the values still showed an increase in eastward progression for the cold front. At this point in the inquiry an explanation doesn't seem obvious but this will be discussed later. At 1930 GMT the two fronts were about 30 miles apart near Pittsburgh and only 10 miles apart at Erie.

In the following hour (1930–2030 GMT) the cold front overtook the warm front and approximately 300 miles of front occluded from a point over Lake Erie southward through Pennsylvania to a point about 50 miles north of Lynchburg, Va. The cold front had moved 38 miles along the Erie line during the past hour and 35 miles along the Pittsburgh line. These values represent the distance between the position of the cold front at 1930 and occlusion at 2030 GMT.

On the basis of similar measurements, the warm front would appear to have moved 30 miles along the Erie line, but this is doubtful because the cold front must have overtaken the warm front some 13 to 15 minutes after the 1930 GMT observation. This, of course, is based upon the assumption of no change in rate of movement of the cold front, an assumption for which there is support. The distance from the cold front at 1930 to the occlusion at 2030 GMT, was 38 miles, which coincides with the rate of cold front movement during the previous hour. Curiously the warm front did not move any measurable distance from its previous position just west of Blairsville on the Pittsburgh line, and yet the cold front advanced through this same region with no decrease in speed.

The analysis was carried for 1 hour beyond 2030 GMT to note what happened to the speed of the front, now an occlusion line. During the hour ending 2130 GMT the occluded front moved 35 miles along the Erie line while the movement along the Pittsburgh line was only 5 to 10 miles. Thus for 1 hour the occluded front continued to move at the speed of the "old" cold front along the Erie line; but at the end of the following 3 hours its rate of motion had decreased to about 22 m. p. h. On the Pittsburgh line the occluded front finally got over the top of the highest ridges east of Blairsville and descending into more open country accelerated to a rate of 18 m. p. h. for the next 3 hours.

FRONTAL MOTIONS AND TOPOGRAPHY

The question arises as to just how well the influence of topography fits the facts as brought out in this short investigation. On the face of it, the action of the warm and cold fronts as related to the influence of topography seems contradictory. It might be worth while to review the preceding paragraphs then, to see if there is any consistent explanation for the situation which has been noted.

For 6 hours in the open countryside of northern Ohio the warm front movement averaged around 26 m. p. h. then slowed down to 18 m. p. h., in the region east of Pittsburgh, and apparently came to a halt for a time at Blairsville. The warm front at the Erie line continued on for some time at a 30 m. p. h. pace before slowing down to 25 m. p. h. for 1 hour. It then resumed the 30 m. p. h. pace until overtaken by the more rapidly moving cold front, after which time, it moved as an occluded front which decelerated to 22 m. p. h. during the last 3 hours of this investigation.

The explanation of the movement of the section of the warm front along the southern shore of Lake Erie must involve the facts that the terrain is comparatively smooth in that region, the hills in that area are approximately parallel to the direction of motion of the storm center,

and the storm circulation was such that the air moved cyclonically around the south shore of Lake Erie to approach Erie, Pa., with very little decrease in speed. All this adds up to the frontal behavior noted in that region.

If it is assumed that the upper air synoptic pattern did not change appreciably, the decrease in the speed of the advancing cold air after the occlusion process began may be attributed mainly to three factors which were operating in the lowest levels. In the first place, after occlusion had started, the retreating cold air now to the east of the advancing cold front, being denser than the occluded warm sector air that had previously been in this position relative to the front, offered increased resistance to the advancing cold air.

Secondly, the eastward component of velocity of air in the retreating cold mass was much less than in the warm mass. Hence, in resisting the change in momentum that would have been required for the front to continue to advance at its previous speed, the retreating cold air tended to slow down the advancing cold air.

Thirdly, after occlusion started the field of solenoids became less pronounced than before, due to the density contrast being less between the cold air masses than between the cold and warm air. The net effect of the weakening of the solenoidal field across the front was to decrease the speed of the advancing cold air in the lowest layers.

From the region of Erie southward the picture was quite different as has been shown by the measurements of the frontal speeds along the line through Pittsburgh. As noted earlier, the fronts moved uphill through western Pennsylvania and approached the vicinity of Blairsville. There the warm front slowed down almost to a halt, but the cold front moved through this same region with no decrease in speed until the time of occlusion. Undoubtedly the warm front behaved as it did because of some relationship between the depth of the retreating cold air (easterly side of the warm front) and the height of the ridges.

To explain, consider a mass of air of considerable depth compared to the vertical irregularities of the terrain over which it is passing (these irregularities are assumed to be of the magnitude and smoothness of the Allegheny, as contrasted with the Rocky Mountains); it would appear that a mass of cold air could move out of the mountains as a unit. Figure 3, for instance, illustrates what is being described. In the lower right hand corner the depth of

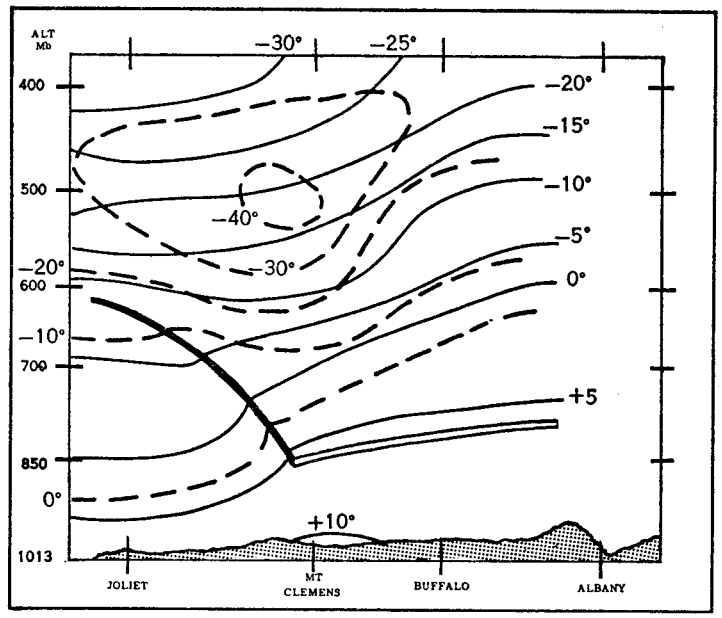

FIGURE 4—Atmospheric cross section, 1500 GMT, October 7, 1951.

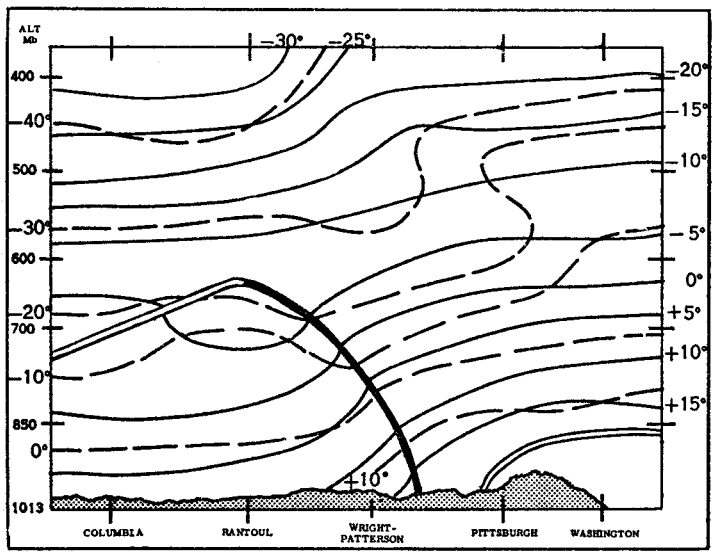

FIGURE 3—Atmospheric cross section, 1500 GMT, October 7, 1951. Thick solid lines and double lines are fronts. Thin solid lines are isotherms of air temperature (° C.) while dashed lines are isotherms of dew point temperature (° C.).

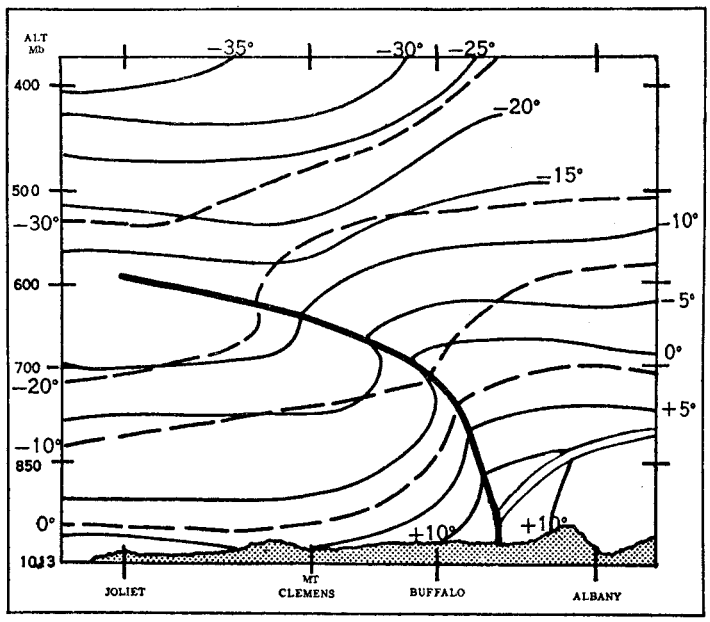

FIGURE 5—Atmospheric cross section, 0300 GMT, October 8, 1951.

the cold air mass exceeds the height of the generalized mountain range.

Now consider the air particles in the cold air as moving eastward in the space defined by the surface of the earth and the frontal boundary above. According to the principle of continuity, the air particles above the mountain ridges would move on eastward to be replaced by other particles moving up and out of the valleys, thereby helping to maintain the flow to the east. So long as this transfer process continues, mass is gradually shifted from the west toward the east and so the intersection of the front with the ground will move along (as a warm front) in the direction of the moving air particles. This process should continue just so long as there is an unimpeded flow of air particles.

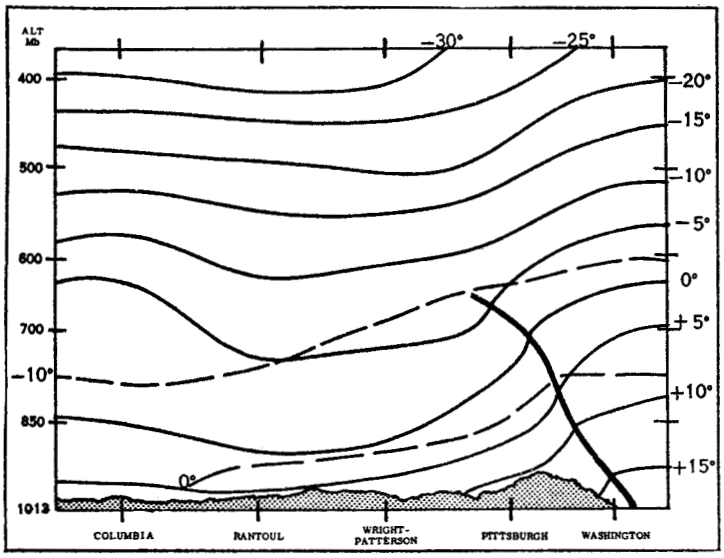

FIGURE 6—Atmospheric cross section, 0300 GMT, October 8, 1951.

This movement of air particles should diminish as the depth of the cold air mass decreases and, relatively, the blocking effect of the ridges increases. The ultimate result should be that the cold air at the surface of the earth should stop, or almost stop, moving until some new force is brought into play. This may be what happened when the warm front came to a near halt as previously noted.

The advancing cold front from the west was able to make good progress through eastern Ohio as it did not move into the rough country, east of Pittsburgh, until the last hour or so before occluding. Here again, the depth of the advancing cold air was greater than the height of the topography below so that no retardation was noted until the cold air reached the highest ridges. By then, a greater amount of cold air was in mountainous country where, because of friction and disruption of flow, the push of the cold air behind the advancing front was reduced. The acceleration of the cold front for a time before the occluding process was related to the channeling effects produced by the ridges which, for a time, were practically tangent to the surface isobars.

Once the cold air got over the high ridges it had to perform work on the retreating cold air mass to the east and so, as was explained previously, the front decelerated.

VERTICAL STRUCTURE OF THE FRONTS

At the time this article was being planned it was thought that it would be a good idea to prepare cross sections of

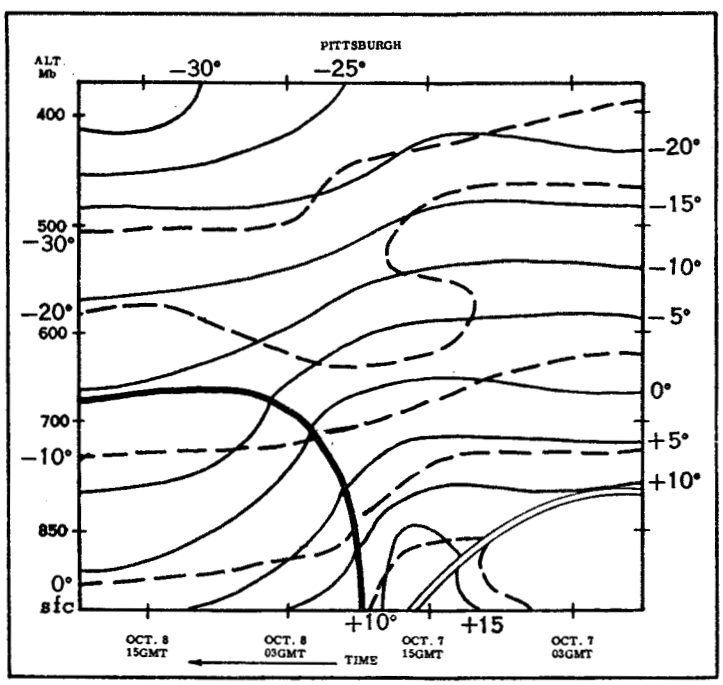

FIGURE 7—Time cross section, Pittsburgh, Pa.

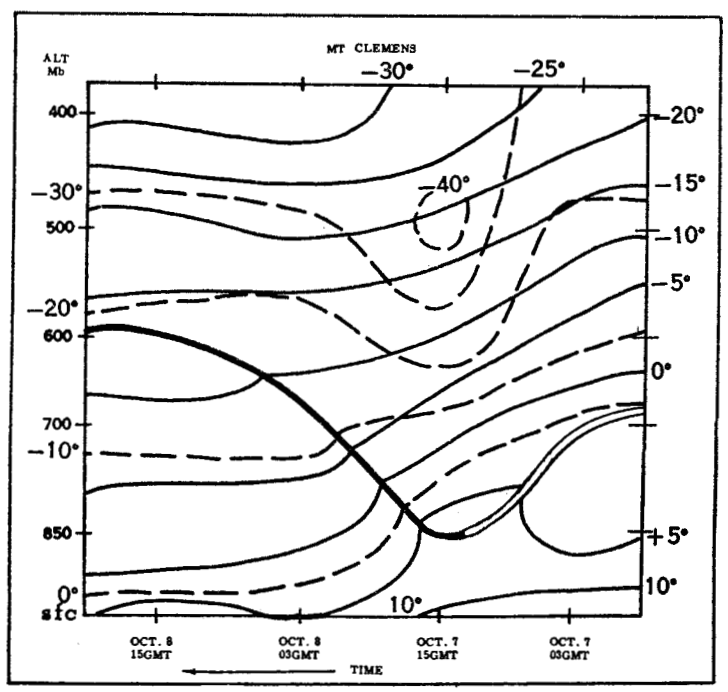

FIGURE 8—Time cross section, Mt. Clemens, Mich.

the occlusion because it was believed that the fortuitous timing of regular upper air observations might possibly result in some detailed information on the process. However, the upper air picture turned out to be quite typical in this case. For instance, figure 3, shows the vertical structure of the open wave before the occluding took place and there isn't much about it worthy of special comment except, perhaps, its resemblance to the classical model found in any good text.

The salient feature of figure 3 is the tongue of dry air above the cold dome. This stream of air reached its lowest elevation in the region immediately east of the cold front, acting much like water flowing down the side of a smooth hill. This dipping toward the earth's surface of the dew point lines and at the same time the opposing bulge, outward from the surface, of the isotherms of the air temperature can be interpreted as evidence that the air was moving over the top of the cold dome and descending the forward portion of the cold front.

Figure 4 covers the same time as the preceding figure but represents a slice through the atmosphere to the north of the Low which was approaching Mt. Clemens, Mich., from the southwest. A glance at figure 1 will aid in understanding why the frontal surfaces show up as they do in this cross section. As noted in the previous paragraph there is a stream of dry air above the advancing cold front but in this latitude the mass of dry air is considerable and is displaced more downstream than one might normally expect. Its location corresponds to a sector of the storm to the north or northwest of the tip of the wave. To the east of Mt. Clemens the isopleths of temperature and dew point looping upward indicate the influx of warm, moist air to high levels.

The next cross section (fig. 5) is interesting because it is somewhat of a "snapshot" of the occluding process as it was operating at the time of the 0300 GMT sounding. At first glance no action appears to be underway except that the cold air was advancing into the retreating cold air; but a closer look at details indicates that the greatest lifting of warm air was occurring in the narrow strip of space adjacent to the leading edge of the cold front, that is, from the point of intersection of the two fronts upward along the front to above the cold air over Mt. Clemens. From this last point to Joliet, Ill., the indicated cooling was a product of the cold air in the upper trough.

Figure 6 is a picture of conditions aloft 12 hours after the time of figure 3. As with figure 5 the lifting was still most active in the region ahead of the advancing front which, at this time and latitude, was still acting as a cold front. Figures 7 and 8 are included to summarize by time cross sections the passage of events at two particular spots; the section at Pittsburgh sums up the activity typical of a station south of the center of the open wave, while the Mt. Clemens section depicts the changes that took place above a station at all times in the cold air to the north or northwest of the peak of the wave.

U. S. GOVERNMENT PRINTING OFFICE: 1952